

## **NROM FLASH MEMORY CELL WITH INTEGRATED DRAM**

### **TECHNICAL FIELD OF THE INVENTION**

[0001] The present invention relates generally to memory devices and in particular the present invention relates to dynamic random access memory and nitride read only memory flash memory architecture.

### **BACKGROUND OF THE INVENTION**

[0002] Memory devices are typically provided as internal, semiconductor, integrated circuits in computers or other electronic devices. There are many different types of memory including random-access memory (RAM), read only memory (ROM), dynamic random access memory (DRAM), synchronous dynamic random access memory (SDRAM), and non-volatile flash memory. One type of flash memory is a nitride read only memory (NROM). NROM has some of the characteristics of flash memory but does not require the special fabrication processes of flash memory. NROM integrated circuits can be implemented using a standard CMOS process.

[0003] DRAM's are the most cost-effective, high-speed memory. They have an almost indefinite number of read/write cycles. DRAM's are also available in very high-density configurations. Some drawbacks to DRAM's, however, is that they can only store data for a short time without being refreshed and, once power is removed, the data is lost.

[0004] Flash memory devices do not require refreshing and can store data indefinitely after the power is removed. These devices, however, have a relatively slow write operation when compared to a DRAM. An additional drawback is that flash memory devices have a limited number of read/write cycles.

[0005] Attempts have been made at combining DRAM or SRAM with non-volatile memory. These devices have an area of DRAM or SRAM cells and an area of non-volatile memory cells. This either increases the size required for a given amount of memory or decreases the memory density possible on a die.

[0006] For the reasons stated above, and for other reasons stated below which will become apparent to those skilled in the art upon reading and understanding the present specification, there is a need in the art for a memory device having the attributes of both DRAM and non-volatile memory.

## **SUMMARY**

[0007] The present invention encompasses a memory device comprising a dynamic random access memory (DRAM) capacitor and a nitride read only memory (NROM) transistor. The DRAM capacitor provides a dynamic mode of operation and the NROM transistor provides a repressed non-volatile random access memory (NVRAM) mode of operation. The NROM transistor is coupled between the capacitor and a bit/data line and acts as a transfer gate for the capacitor to the bit/data line.

[0008] Further embodiments of the invention include methods and apparatus of varying scope.

## **BRIEF DESCRIPTION OF THE DRAWINGS**

[0009] Figure 1 shows a schematic diagram of one embodiment of a DRAM cell with a repressed NROM cell of the present invention.

[0010] Figure 2 shows a cross-sectional view of one embodiment of two DRAM cells of the present invention with NROM transfer gates.

[0011] Figure 3 shows a cross-sectional view of one embodiment of a write operation to the NROM cell using an electron tunneling process.

[0012] Figure 4 shows a cross-sectional view of one embodiment of an erase operation of an NROM cell with a charged DRAM capacitor.

[0013] Figure 5 shows a cross-sectional view of one embodiment of a read operation of an NROM cell when the cell is erased.

[0014] Figure 6 shows a cross-sectional view of one embodiment of a read operation of an NROM cell when the cell is charged.

[0015] Figure 7 shows a flow chart of one embodiment for accessing the memory device of the present invention.

[0016] Figure 8 shows a block diagram of an electronic system of the present invention.

### **DETAILED DESCRIPTION**

[0017] In the following detailed description of the invention, reference is made to the accompanying drawings that form a part hereof and in which is shown, by way of illustration, specific embodiments in which the invention may be practiced. In the drawings, like numerals describe substantially similar components throughout the several views. These embodiments are described in sufficient detail to enable those skilled in the art to practice the invention. Other embodiments may be utilized and structural, logical, and electrical changes may be made without departing from the scope of the present invention. The following detailed description is, therefore, not to be taken in a limiting sense, and the scope of the present invention is defined only by the appended claims and equivalents thereof.

[0018] The DRAM cell with repressed NROM cell of the present invention provides a one transistor/one capacitor memory cell that has two modes of operation. The first mode is a dynamic random access memory mode. The second mode is a non-volatile random access memory (NVRAM) mode utilizing the NROM transfer device as an NROM cell device.

[0019] Figure 1 illustrates a schematic diagram of one embodiment of the DRAM cell with the repressed NROM memory of the present invention. The embodiment is comprised of a DRAM capacitor 101 that is connected between ground and the NROM memory cell 108. The NROM cell 108 acts as a transfer gate for the DRAM capacitor 101 since it is between the bit/data line 105 and the DRAM cell 101. A word line 107 connects the control gates of all of the NROM cells in a row of cells of a memory array. The bit lines 105 and word lines 107 are well known in the art and are not discussed further.

[0020] When the memory device 100 is in the NVRAM mode, the NROM cell 108 can act as a non-volatile memory cell whose data is completely independent of the DRAM cell 101. In this mode, the NROM cell 108 operates with the same read/program/erase characteristics as a flash memory cell. The read, program, and erase operations of flash memory cells are well known in the art and are not discussed further.

[0021] Also in the NVRAM mode, the NROM cell 108 can act as a shadow memory cell such that a charge stored in the DRAM cell 101 is stored in the NROM cell 108. By applying a large negative voltage to the word line 107 for a few milliseconds, the data from the DRAM capacitor 101 is written into the NVRAM NROM cell 108. Thus, when power is removed, the data from the DRAM is stored in a non-volatile fashion. In this embodiment, the memory device's controller (discussed subsequently) executes a programming operation of the NROM cell 108 when a power-down is detected. This enables the memory device 100 to act as a NVDRAM.

[0022] If the DRAM capacitor 101 is not charged during this programming operation, any charge in the nitride trapping layer would remain. This is due to the voltage difference across the gate insulator between the source and drain regions not being large enough to cause tunneling.

[0023] When the memory device 100 is in the DRAM mode, the data is stored and read from the DRAM cell 101. The cell 101 has to be refreshed in a normal DRAM fashion as is well known in the art. In this mode, the NROM cell 108 acts as a transfer gate for the data to be read on the bit line 105.

[0024] Figure 2 illustrates a cross-sectional view of two DRAM cells 205 and 206 of the present invention with NROM transfer gates 210 and 211 respectively. Both NROM transistors 210 and 211 are substantially similar; therefore the description of one applies to the other.

[0025] Each NROM cell 210 and 211 is comprised of two n<sup>+</sup> doped regions 207 and 209 in the substrate. These regions are the source and drain areas for each NROM transistor 210 and 211.

[0026] Between the doped regions 207 and 209 is the nitride storage layer 201. In one embodiment, this layer is an oxide-nitride-oxide (ONO) composite layer. Alternate embodiments use other gate insulators besides the ONO structure shown. These structures include oxide-nitride-aluminum oxide composite layers, oxide- aluminum oxide-oxide composite layers, oxide, silicon oxycarbide-oxide composite layers as well as other composite layers.

[0027] In still other alternate embodiments, the gate insulator could include thicker than normal silicon oxides formed by wet oxidation and not annealed, silicon rich oxides with inclusions of nanoparticles of silicon, silicon oxynitride layer that are not composite layers, silicon rich aluminum oxide insulators that are not composite layers, silicon oxycarbide insulators that are not composite layers, silicon oxide insulators with inclusions of nanoparticles of silicon carbide, in addition to other non-stoichiometric single layers of gate insulators of two or more commonly used insulator materials such as Si, N, Al, Ti, Ta, Hf, Zr, and La.

[0028] The control gate 203 is a polysilicon structure formed over the gate insulator layer 201. The control gate 203 is also the word line that is coupled to other NROM transistors. The bit/data line is coupled to the common source/drain region 209 that is an element of both transistors 210 and 211. The bit/data line is eventually coupled to sense amplifiers in order to read the data stored in the NROM/DRAM cells. The sense amplifiers are discussed subsequently with reference to the system of Figure 7.

[0029] Data is written into the DRAM cell 205 or 206 when the word line of the respective NROM memory cell 210 or 211 is at a first potential. Data is written into the NROM cell 210 or 211 when the word line is at a second potential that is higher in magnitude than the first potential but less than the maximum operating voltage of the transistor.

[0030] Figure 3 illustrates a cross-sectional view of one embodiment of a write operation to an NROM cell using an electron tunneling process. This embodiment uses a positive gate voltage applied to the control gate 301 and  $-1/2$  Volt source bias 305. The voltage difference across the gate insulator 310 between the source 305 and drain 306 regions, in

one embodiment, is large enough to allow direct tunneling to the nitride trapping layer 303. Alternate embodiments use other voltages. In this embodiment, the substrate 320 is grounded.

[0031] In this embodiment, the substrate 320 is a p-type conductivity material and the source/drain regions 305 and 306 are n-type conductivity material. However, these types of silicon may be reversed in alternate embodiments. In such an embodiment, the gate voltage will be a negative bias while the source bias will be positive.

[0032] Figure 4 illustrates a cross-sectional view of one embodiment of an erase operation of an NROM cell. In this embodiment, electron trapping and detrapping is only employed at one end of the channel for the NVRAM memory function.

[0033] To erase the data stored in the NROM cell 400 the DRAM capacitor 401 is fully charged and a negative voltage is applied to the word line and gate 402 of the NROM device 400. This causes the electrons to tunnel out of the nitride charge storage layer 403 at one end 405 of the NROM device 400. There are relatively few electrons trapped in this layer 403 while the charge stored on the DRAM capacitor 401 consists of a 50 fC charge. This is equivalent to hundreds of thousands of electrons. Therefore, the few electrons discharged from the nitride layer 403 during this erase operation will not change the potential of the DRAM capacitor 401. If the erase operation is not performed, the nitride layer 403 will remain charged.

[0034] A read operation of the memory device of the present invention is subsequently described with reference to Figures 5 – 7. Figure 7 illustrates a flow chart of a method for accessing the memory device.

[0035] After the system in which the memory device is located is initialized, a check is performed 701 to determine whether the memory cells are being accessed as a DRAM (dynamic mode) or as a non-volatile memory (repressed mode). In one embodiment, the dynamic and repressed memory modes of the present invention are signaled by the magnitude of the voltage applied to the word line.

[0036] If the memory cells are to be operated as a DRAM 703, either a normal read or write operation can be performed. Both the read and write DRAM operations are well known in the art and are not described further. As long as the voltage applied to the word line remains in the normal operating range of the transistor (e.g., 3.0 V), the tunneling voltages of the nitride layer are not exceeded and the charge state of the nitride layer remains unchanged.

[0037] If a read operation is to be performed in the NVRAM mode of operation, the stored potential charges in the NROM nitride layer affect the threshold voltage of the transfer gate. This fact can be used to distinguish between digital values stored in the memory cell during the NVRAM mode of operation. In other words, a difference in threshold voltage of the transfer device has no effect on the potential transferred to the bit line. But it will affect the rate at which the charge is transferred. The difference in threshold voltage,  $V_T$ , and resistance of the transfer device determines only the current. The DRAM sense amplifiers respond only to potential differences, thus small changes in  $V_T$  has no significant impact on the operation of the memory cell in the DRAM mode. This is because the applied voltage is as high above  $V_T$  as possible.

[0038] The word line capacitance of the memory device of the present invention is comparable to a conventional DRAM cell. During operation as a normal DRAM, the transistor just transfers a charge from the storage capacitor onto the bit line. A difference in  $V_T$  of the transfer device has no effect on the amount of charge transferred, only the rate at which it is transferred. The difference in threshold voltage may determine only the current but the sense amplifier responds to charge differences in DRAM operation. Smaller differences in threshold voltage may slightly affect the response time but not the final charge sensed. This is the determining factor in DRAM operation.

[0039] During normal DRAM operation, the word line is driven to a voltage as far as possible in excess of the threshold voltage of the transfer device. This minimizes the resistance of the transfer device which could typically be a few thousand ohms. This results in the charge being transferred to the bit line capacitance in a sub-nanosecond time period and the sense amplifier subsequently responding quickly.

[0040] Reading the NROM transistor during the NVRAM mode of operation 705, the DRAM sense amplifier can be employed to determine current differences by observation of the response time of the sense amplifier. This is accomplished by using small transfer device currents and observing long response times. The word line is driven to a voltage only slightly in excess of the threshold voltage so that the current,  $I_{DS}$ , through the transfer device is small. This results in a very slow response of the sense amplifier. In this manner, differences in threshold voltage can be determined by measuring the differences in response time.

[0041] In order to detect the repressed memory in the NVRAM mode, sensing time should be increased. Using a x16 memory structure, it might take as long as 0.1 minute to totally download the repressed data stored in a 64x16 memory. This is indicative of an individual bit access time of about 1.5 microseconds.

[0042] In an alternate embodiment, the repressed memory state stored in the nitride layer can be determined as a separate operation by independently measuring the threshold voltage of the transfer device. The storage capacitor can first be fully charged and then the current supplied by the transfer device to the sense amplifier can be measured at many different gate voltages. This numerical data can then be used to calculate the threshold voltage.

[0043] Figure 5 illustrates a cross-sectional view of one embodiment of a read operation of an NROM cell when the cell is erased. As discussed above, data stored in the DRAM capacitor represents the presence or absence of a stored charge and the data in the NROM nitride layer 501 represents first and second values of the threshold voltage of the transistor. In the latter case, the presence or absence of the stored charge are determined by the sense amplifier while the first and second values are calculable based on numerical data generated by the sense amplifier.

[0044] Since the nitride layer 501 of Figure 5 does not have a stored charge, the threshold voltage of the NROM transistor 500 has a lower threshold voltage than a programmed cell. When a bias that is slightly larger than  $V_T$  is applied to the wordline 502, a large  $I_{DS}$  results. The response time of the sense amplifier is then measured. A fast



response time indicates the larger current and, thus, the fact that the NROM cell is not programmed.

[0045] Figure 6 illustrates a cross-sectional view of one embodiment of a read operation of an NROM cell when the nitride layer 601 is storing a charge. In this embodiment, the NROM transistor has a higher threshold voltage in the indicated channel region 603 due to the stored charge. When a bias that is slightly larger than  $V_T$  is applied to the word line 602, a smaller  $I_{DS}$  results. The response time of the sense amplifier is then measured. A longer response time indicates a smaller current than an erased cell and, thus, the fact that the NROM cell is programmed.

[0046] Figure 8 illustrates a functional block diagram of a memory device 800 that can incorporate the DRAM with repressed NROM memory cells of the present invention. The memory device 800 is coupled to a processor 810. The processor 810 may be a microprocessor or some other type of controlling circuitry. The memory device 800 and the processor 810 form part of an electronic system 820. The memory device 800 has been simplified to focus on features of the memory that are helpful in understanding the present invention.

[0047] The memory device includes an array of memory cells 830 that can be NROM cells integrated with DRAM cells. In one embodiment, all of the cells of the array are integrated NROM/DRAM cells of the present invention. Alternate embodiments have other quantities of integrated NROM/DRAM cells.

[0048] The memory array 830 is arranged in banks of rows and columns. The control gates of each row of memory cells is coupled with a wordline while the drain and source connections of the memory cells are coupled to bitlines. As is well known in the art, the connection of the cells to the bitlines depends on whether the array is a NAND architecture or a NOR architecture.

[0049] An address buffer circuit 840 is provided to latch address signals provided on address input connections A0-Ax 842. Address signals are received and decoded by a row decoder 844 and a column decoder 846 to access the memory array 830. It will be appreciated by those skilled in the art, with the benefit of the present description, that the

number of address input connections depends on the density and architecture of the memory array 830. That is, the number of addresses increases with both increased memory cell counts and increased bank and block counts.

[0050] The memory device 800 reads data in the memory array 830 by sensing voltage or current changes in the memory array columns using sense/buffer circuitry 850 as described previously with reference to Figures 5 and 6. The sense/buffer circuitry, in one embodiment, is coupled to read and latch a row of data from the memory array 830. Data input and output buffer circuitry 860 is included for bi-directional data communication over a plurality of data connections 862 with the controller 810). Write circuitry 855 is provided to write data to the memory array.

[0051] Control circuitry 870 decodes signals provided on control connections 872 from the processor 810. These signals are used to control the operations on the memory array 830, including read, write, and erase operations. The control circuitry 870 may be a state machine, a sequencer, or some other type of controller.

[0052] Since the NROM memory cells of the present invention use a CMOS compatible process, the memory device 800 of Figure 8 may be an embedded device with a CMOS processor.

[0053] The memory device illustrated in Figure 8 has been simplified to facilitate a basic understanding of the features of the memory. A more detailed understanding of internal circuitry and functions of DRAM and NROM memories are known to those skilled in the art.

## **CONCLUSION**

[0054] In summary, the embodiments of the present invention provide a one transistor/one capacitor memory device having multiple modes of operation. The memory device can operate in a DRAM mode in which the device is written and read from in a normal DRAM manner. The device can also operate in a repressed, non-volatile random access memory mode (NVRAM), using an NROM transfer device, where the NVRAM can be a completely separate memory or to shadow and/or back-up data stored in the DRAM.

**[0055]** Although specific embodiments have been illustrated and described herein, it will be appreciated by those of ordinary skill in the art that any arrangement that is calculated to achieve the same purpose may be substituted for the specific embodiments shown. Many adaptations of the invention will be apparent to those of ordinary skill in the art. Accordingly, this application is intended to cover any adaptations or variations of the invention. It is manifestly intended that this invention be limited only by the following claims and equivalents thereof.